

ELECTRONIC FUNDAMENTALS

THEORY LESSON 18

BASIC FILTERS AND TIME CONSTANTS

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18-6. Time Constants



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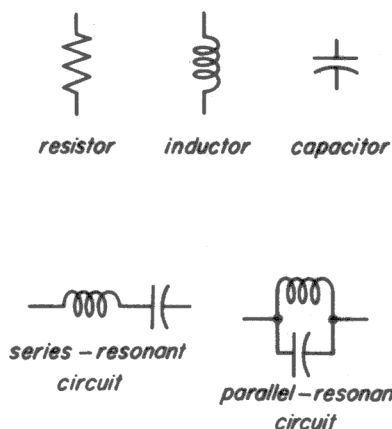
Theory Lesson 18

INTRODUCTION

A filter is a device for separating mixed substances. A filter can be made to select what we want from a mixture and to reject the rest of the mixture. Many kinds of filters are used all around us. For example, the filter paper or cloth in a coffee maker lets the coffee pass through and holds back the coffee grounds. Many automobiles have oil filters to remove solids from the oil. Filters are placed over camera lenses to block certain colors or light rays in picture making. In radio and television, filters are used to separate one kind of current from another, to prevent unwanted signals from interfering with the signals of a program we wish to hear or see, to "smooth out" the pulsations in pulsating d.c., and for many other purposes. The action of an electrical filter is a little harder to understand than that of the coffee filter, but the basic idea is the same: each filter separates what is wanted from what isn't wanted.

Electrical filters used in radio and television are made from combinations of three kinds of parts with which you are already familiar: resistors, capacitors, and inductors. In addition, parallel-resonant and series-resonant circuits that you studied in Lesson 16 are used in filters. From different combinations of these parts and circuits, four main classes of electrical filters can be made to separate alternating current or voltage of a certain range of frequencies from alternating current or voltage of other frequencies. The types of filters are:

1. *Low-pass filters* that permit low frequencies to pass and stop high frequencies.
2. *High-pass filters* that permit high frequencies to pass and stop low frequencies.
3. *Band-pass filters* that permit a certain



building blocks of filters

Fig. 18-1

band of frequencies to pass and stop all other frequencies.

4. *Band-rejection filters* that block a certain band of frequencies and permit all other frequencies to pass.

18-1. FILTER ACTION OF COMPONENTS

Figure 18-1 shows the basic parts of all electrical filter circuits used in radio and television. They are used as building blocks to make up the simplest and the most complicated filter circuits. Each part that makes up a filter is used to produce a particular effect in the filter circuit. To understand the total effect of a filter, it is necessary to know what each part does in the circuit. So, we will review what we know about these building blocks of filters.

A resistor by itself has no filtering action, because it offers equal opposition to the flow of d.c. and to the flow of a.c. of any frequency. However, a resistor combined with a capacitor does have filter action, as you will see shortly. In addition, resistance inserted in a tuned circuit reduces the Q of

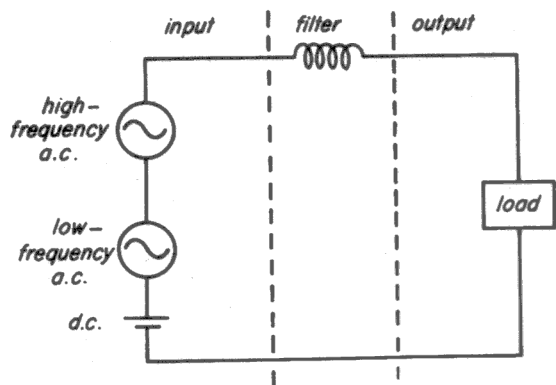


Fig. 18-2

the circuit which decreases selectivity and broadens the bandpass of the circuit. This was discussed in Lesson 16 and will be discussed further in this lesson and in lessons to come.

Capacitors and inductors *discriminate* against frequency, which means only that they act differently to a.c. of high frequencies by permitting one frequency to pass and stopping another. For example, (Fig. 18-2 shows three voltage sources d.c.,) low-frequency a.c., and high-frequency a.c., *coupled* to a load through a filter choke. (When one circuit is connected to another, we say that it is coupled.) As you know, inductive reactance increases as frequency increases, so the higher the frequency, the greater will be the opposition due to inductive reactance. Therefore, the series-connected choke will discriminate against a.c. of high frequencies while it permits a.c. of low frequencies and d.c. to pass with little or no opposition to the load.

Series-resonant and parallel-resonant circuits combine capacitance and inductance, the effects of which we have already de-

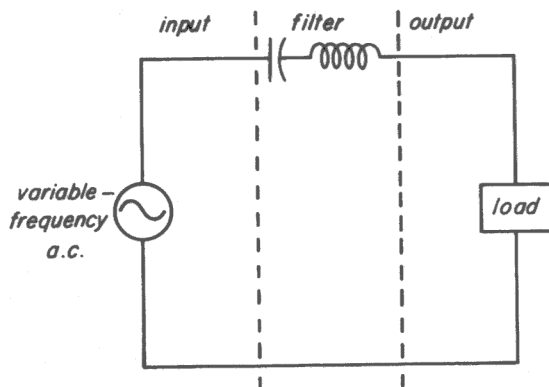


Fig. 18-3

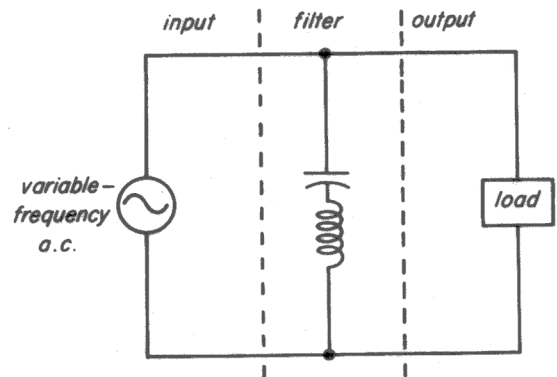


Fig. 18-4

scribed. However, each type of circuit has its own special effect, which causes us to include it among the building blocks of filter circuits. For instance, the special effect offered by a series-resonant circuit is that it offers minimum opposition to the frequency to which it is tuned (the resonant frequency) and great opposition to all other frequencies. When a series-resonant circuit couples a load to a variable-frequency source, as in Fig. 18-3, the filter passes the a.c. of the resonant frequency to the load and rejects alternating current of all other frequencies. When a series-resonant circuit is connected in parallel with the load, as in Fig. 18-4, the a.c. of the resonant frequency takes the low-opposition path through the series-resonant circuit and bypasses the load. In other words, the series-resonant circuit appears as a short circuit at the resonant frequency and no voltage drop can appear across the load.

The special effect that a parallel-resonant circuit produces in a filter is that it offers very high opposition to a current of the resonant frequency and low opposition to currents of all other frequencies. When connected as in Fig. 18-5, a parallel-resonant circuit pre-

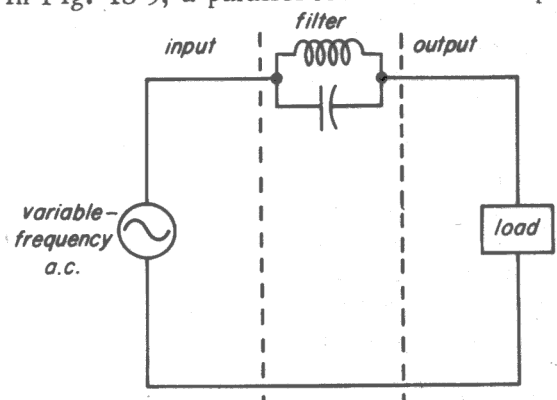


Fig. 18-5

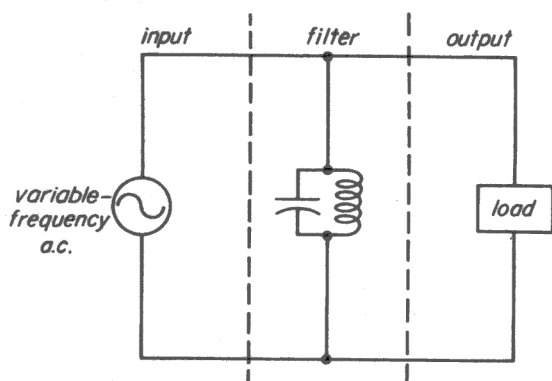


Fig. 18-6

vents the a.c. of the resonant frequency from reaching the load, while it passes a.c. of all other frequencies. However, when the parallel-resonant circuit is placed in parallel with the load, as in Fig. 18-6, the a.c. of the resonant frequency takes the low-opposition path through the load, while currents of other frequencies are bypassed through the parallel-resonant circuit.

18-2. LOW-PASS FILTERS

A low-pass filter is simply a circuit that permits d.c. and the lower a-c frequencies appearing at its input to pass to the output (load) with little or no opposition but blocks the passage of a.c. of higher frequencies. Many different combinations of coils, capacitors, and resistors will produce this result.

As we have seen, the very simplest circuit that will give us low-pass filtering action consists of just one part — either a capacitor connected across the line or an inductor connected in series with the line. However, when we speak of filters we usually have in mind something a little more complicated than a single component. The single component has a very gradual filter action. We usually need something more selective as far as frequency is concerned. Practical low-pass filters often must be able to pass one frequency and block another only a few hundred or a thousand cycles higher. This can be done by combining different components. Simple practical low-pass filters are composed of a series resistor and a shunt capacitor or a series inductor and shunt capacitor.

RC Filter. A resistor and a capacitor can be combined to produce a low-pass filter.

Such a filter is called a resistor-capacitor or RC filter. An RC low-pass filter is shown in Fig. 18-7a. So that we may clearly see the action of this filter, let's remove the load for a moment, as in Fig. 18-7b. This places the resistor and the capacitor in series across the variable a-c voltage source. The voltage divides across the resistor and the capacitor in proportion to the opposition that each offers to the a.c. In Fig. 18-7c, the opposition offered by the resistor is represented by the resistor marked R and the opposition offered by the capacitor is represented by the resistor marked X_C . A typical filter circuit, used in some a.c.-d.c. power supply systems, might have a 1,000-ohm resistor and a 20- μ f capacitor. Using these values, let's see how the voltage divides at different frequencies. We'll start with a frequency of 1 cps. To find the opposition offered by the capacitor, we use the formula:

$$\begin{aligned} X_C &= \frac{159,000}{f C} \\ &= \frac{159,000}{1 \times 20} \\ &= 7,950 \text{ ohms} \end{aligned}$$

The total opposition to 1-cycle a.c. is about 9,000 ohms, with 1,000 ohms across the filter resistor and about 8,000 ohms across the filter capacitor. So, about 1/9 of the voltage is across the filter resistor and 8/9 across the capacitor. When a load is applied across the capacitor most of the 1-cycle a-c voltage reaches the load — provided that the load resistance is ten or more times the capacitive reactance. When 10-cycle a.c. is applied to the filter, the resistance of the filter resistor is still 1,000 ohms but the reactance of the filter capacitor drops to 795 ohms. So less than half of the applied 10-cycle a.c. reaches the filter capacitor and the load. At 100 cps, the capacitive reactance is only 79.5 ohms, so that most of the 100-cycle voltage drops across the resistor and very little reaches the capacitor and the load. The higher the frequency, the lower is the capacitive reactance and the less is the voltage across the capacitor (and load). The

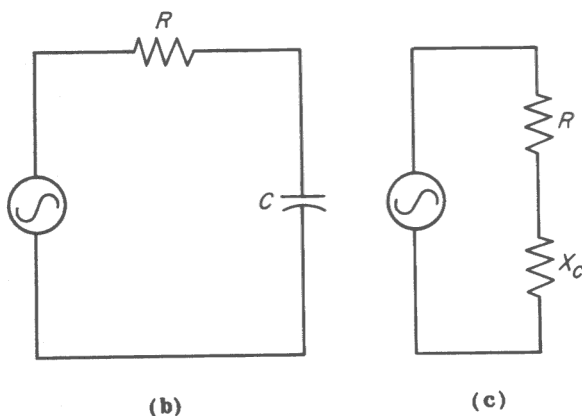
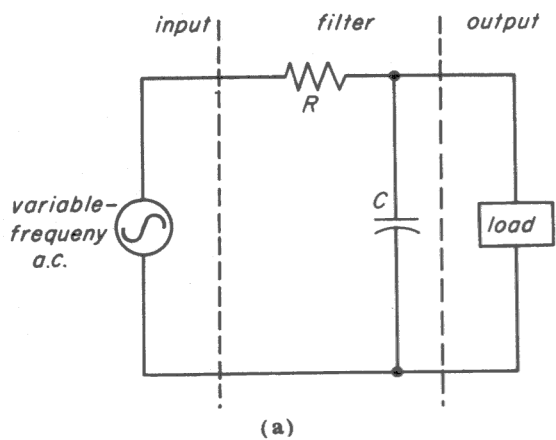


Fig. 18-7

graph in Fig. 18-8 shows how the capacitive reactance and the load voltage vary with frequency.

Thus, the RC circuit is a low-pass filter, since more of the lower-frequency voltages than of the higher-frequency voltages reach the load. The values of R and C we have been using in this discussion make a filter that passes only d.c. and very low a.c. fre-

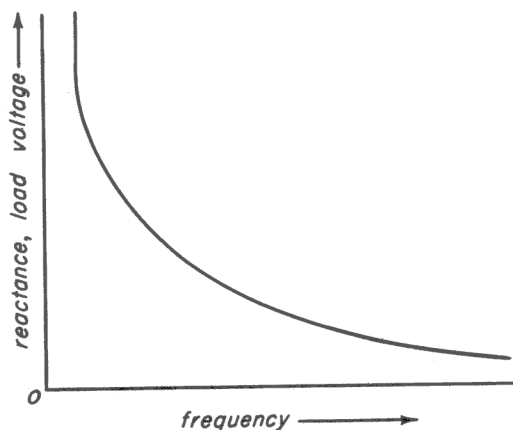


Fig. 18-8

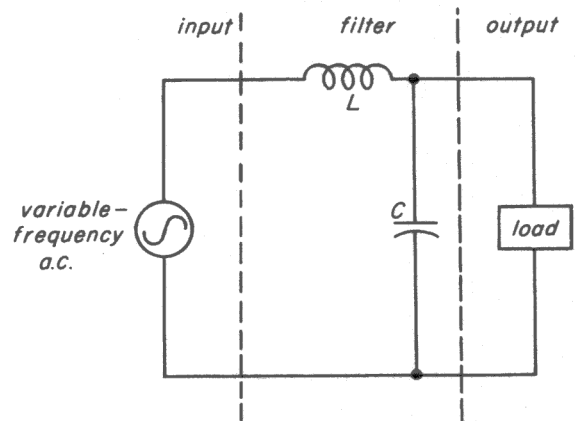
simple L -type low-pass filter

Fig. 18-9

quencies. This is what a power-supply filter must do, for it must pass d.c. (zero frequency) and block 60- or 120-cycle ripple frequencies and their harmonics. (A half-wave rectifier of 60-cycle a.c. produces 60 pulses per second; and a full-wave rectifier produces 120 pulses per second; it is necessary that these frequencies be blocked.) When the capacity of the filter capacitor is decreased, the filter will pass a.c. of higher frequencies. It is important that the capacitive reactance of the filter capacitor at the highest wanted frequency be high compared to the resistance of the filter resistor. However, the RC filter is not very selective to frequency, and its principal use is in circuits where selectivity is not important. It provides inexpensive filtering in some a.c.-d.c. receivers where space and cost are considered more important than a high degree of filtering. One disadvantage of RC power-supply filtering is that power is lost in the filter resistor.

LC Filter. A simple L -type LC filter is shown in Fig. 18-9. It is called L type because one impedance is in series with the line and the other impedance across it, forming an L -shaped connection. It makes no difference which impedance is in series or in shunt with the line; the shape of the connection makes it an L -type filter. However, a low-pass L filter is made up of a series inductor and shunt capacitor, as shown in Fig. 18-9. The operation of the filter is simple. The input-voltage source is in series with filter choke L and filter capacitor C . The output filter voltage appears across C and is passed on to the load, R_L .

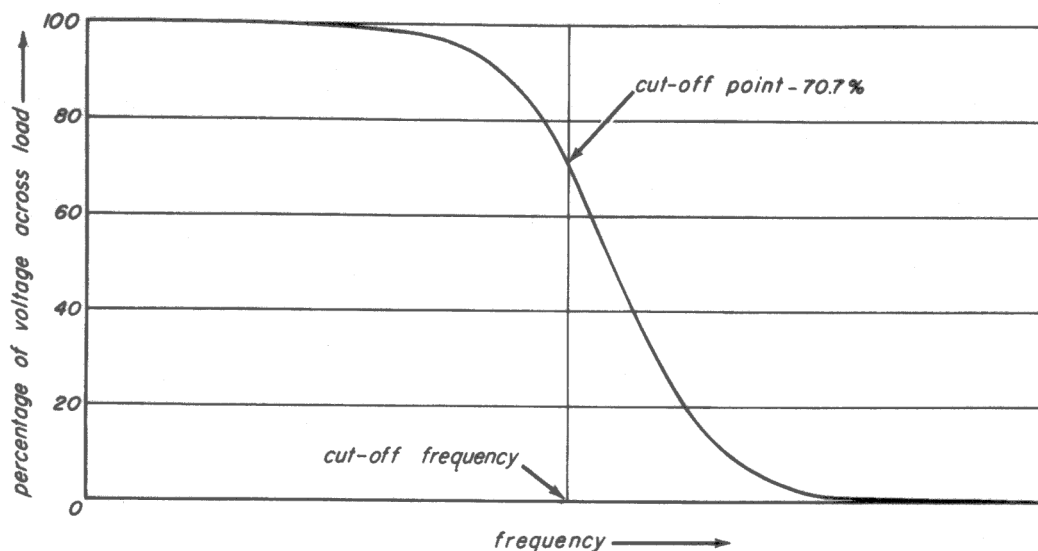


Fig. 18-10

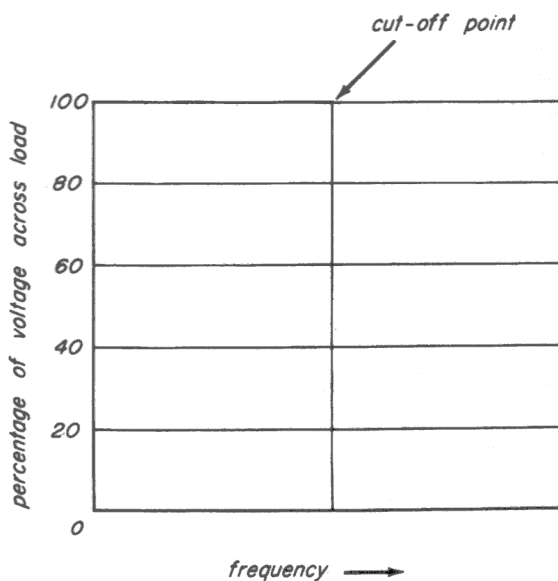
For voltages of low-input frequency, the filter choke L offers a very small inductive reactance to the input voltage, while the filter capacitor C offers a very large capacitive reactance. A small voltage drop appears across L and a very large drop across C . The drop across C is passed on to the load, R_L . Thus, most of the low-frequency input voltage is permitted to pass to the load with very little loss in amplitude.

For voltages of high frequencies, however, the inductive reactance of L becomes large while the capacitive reactance of C is reduced to a very low value. Now most of the input voltage is dropped across L . There is only a small drop across C , so only a very small portion of the input voltage reaches the load.

The action of the LC low-pass filter produces a greater filtering action than does the RC low-pass filter because the inductive and capacitive reactances change inversely, resulting in a sharper cutoff. The curve in Fig. 18-10 shows the percentage of voltage that passes to the load at different frequencies. At zero frequency (d.c.), practically 100 percent of the voltage reaches the load. There is no inductive reactance, so the only opposition to current flow is the resistance of the coil winding, which is so very small compared with the reactance of the capacitor that it can be ignored. The load voltage remains close to 100 percent in the lower-frequency range. As the frequency increases, the reactance of the choke increases, pro-

ducing an increasing voltage drop across L , less across C . As frequency increases further, a frequency will be reached where 70.7% of the voltage reaches C and the load. This point has been chosen as the *cut-off point*, and the frequency at which this point occurs is called the *cut-off frequency*.

An ideal low-pass filter is one that passes all frequencies up to the cut-off frequency and stops all higher frequencies. The curve for such a filter would look like that in Fig. 18-11. All of the voltage of frequencies below cutoff reaches the load and none of the voltage of frequencies above cutoff is per-



ideal low-pass filter curve

Fig. 18-11

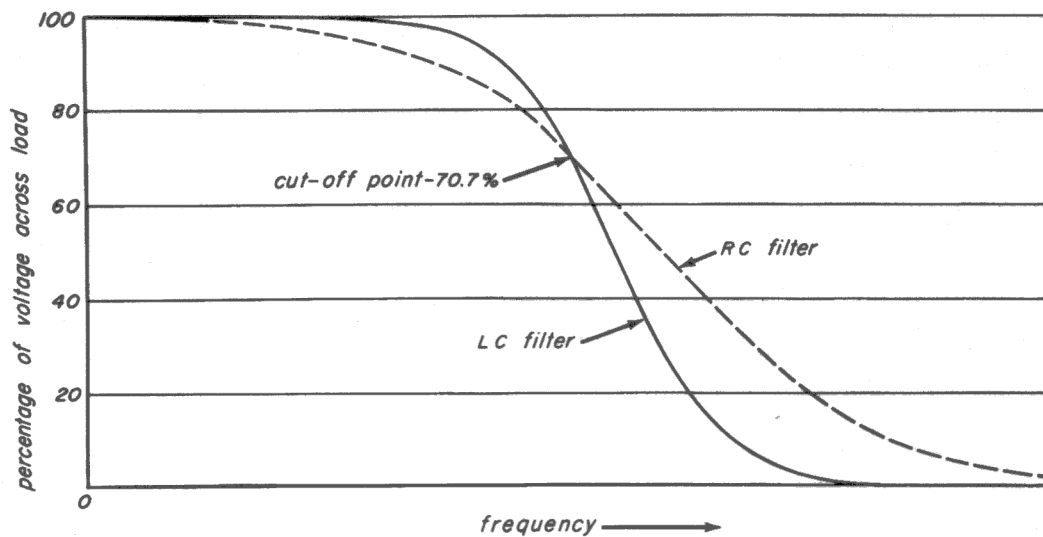


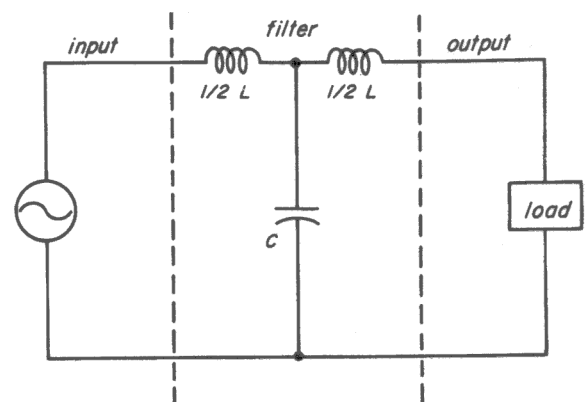
Fig. 18-12

mitted to pass. However, no filter yet designed is efficient enough to pass one frequency and to stop the next. The best that we can expect is that a low-pass filter attenuates (reduces) a.c. of wanted frequencies (those below cutoff) very little while it attenuates a.c. of unwanted frequencies (those above cutoff) as much as possible. This means that the curve of a good low-pass filter should be as steep as possible after the cut-off point. Figure 18-12 shows two curves, one for a low-pass RC filter and the other for a low-pass LC filter. The curves show that the LC filter causes less attenuation of frequencies below cutoff and greater attenuation of frequencies above cutoff than does the RC filter. In comparing these two filters, we say that the LC filter has a *sharper cutoff* than the RC filter. There are filter combinations that provide sharper cutoff than the simple LC filter, as you will see shortly. Such filters are needed when the frequency of the voltage to be stopped is close to the frequency of the voltage to be passed.

T and π -Type Low-Pass Filters. Two other methods of connecting filter components are shown in Fig. 18-13 and 14. Like the L-filter, each of these filters is named for its shape; that in Fig. 18-13 is called a T filter and that in Fig. 18-14 is called a π filter. Notice that the series inductors in the T filter are marked $1/2 L$ and the inductor in the π filter is marked L . This is done to show you that the total inductance in the T filter is equal to the inductance of the π filter.

Note, too, that the two capacitors in the π filter are marked $1/2 C$, and the capacitor in the T filter is marked simply C , to show that the total capacitance in each filter is the same. The values of L and C in these filters depend upon the cut-off frequency and the load impedance. For maximum transfer of power from the voltage source to the load, the load impedance should be equal to the source impedance. However, practical power-supply filters are designed to meet special conditions, which will be discussed later in this course.

Multi-Section Low-Pass Filters. A filter with a sharper cutoff may be made by using more than one section. For example, two or more T or π sections may be combined to produce sharper cutoff (Fig. 18-15). The drawing of the two-section T filter (Fig. 18-15a) shows



T-type low-pass filter

Fig. 18-13

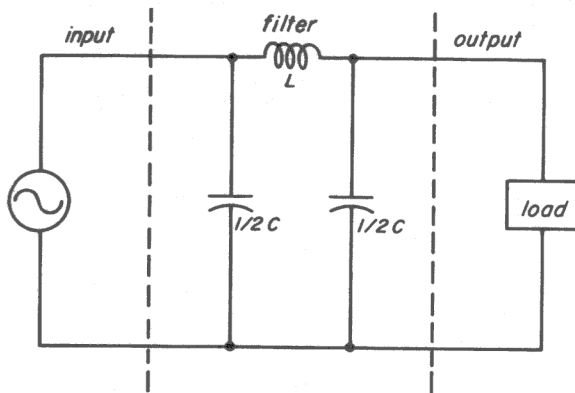
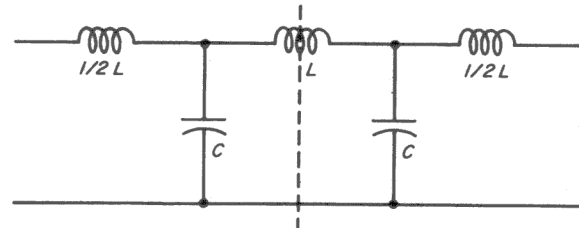
*T - type low - pass filter*

Fig. 18-14

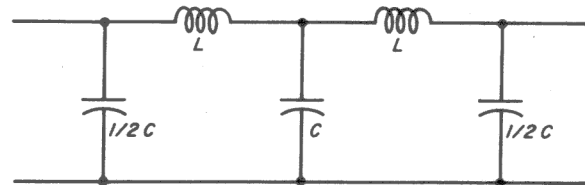
that one-half of the center inductor belongs to the first *T* section and the other half to the second *T* section. The drawing of the two-section π filter (Fig. 18-15b) shows that one-half of the capacitor belongs to the first section and the other half to the second π section.

18.3. HIGH-PASS FILTERS

A high-pass filter works in a way that is exactly opposite to that of the low-pass filter. It passes the a.c. of higher frequencies and blocks the a.c. of lower frequencies that appear at its input. There are as many high-pass filter circuits as there are low-pass filter circuits. One of the simplest high-pass filters is made from a resistor and a capacitor. An *RC* high-pass filter is connected so that the capacitor is in series and the re-

*two - section T - type low - pass filter*

(a)

*two section pi - type low - pass filter*

(b)

Fig. 18-15

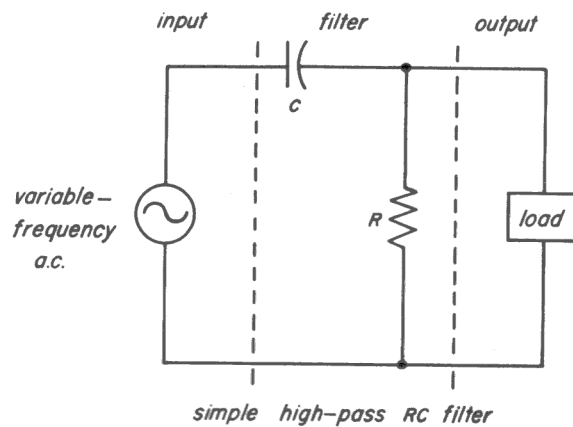
*simple high-pass RC filter*

Fig. 18-16

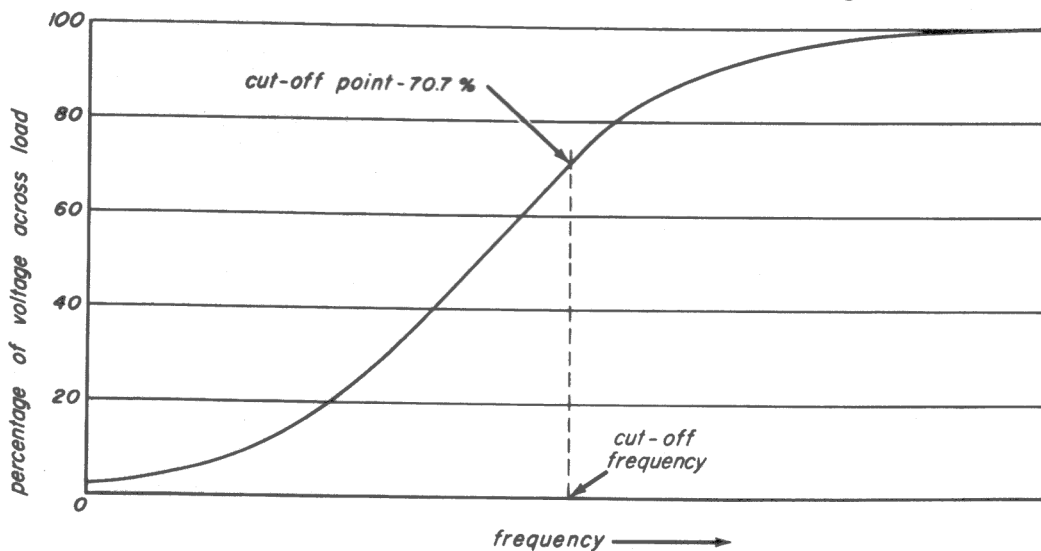


Fig. 18-17

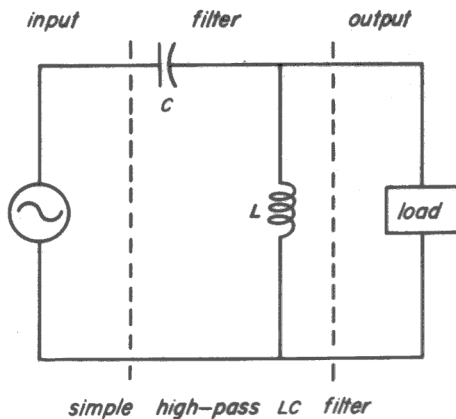


Fig. 18-18

sistor is in parallel with the load (Fig. 18-16). The series capacitor offers high reactance to the unwanted low-frequency a.c. This causes most of the low-frequency a.c. to be dropped across the capacitor, with little or none reaching the load. The capacitor offers little opposition to high-frequency a.c.; it is delivered to the load. A curve (Fig. 18-17) showing the voltage across the load for different frequencies shows that this type of filter does not have a very sharp cutoff.

LC High-Pass Filter. A filter that has a steeper cutoff is the *LC* filter (Fig. 18-18). Because the reactance of the capacitor is so very high for lower frequencies a.c., very little of the low-frequency input voltage appears across the load. However, as the frequency of the input voltage rises, the capacitive reactance decreases and the inductive

reactance increases, permitting more of the higher-frequency voltage to reach the load, as shown in the curve of Fig. 18-19.

High-pass filters are made in *T* and π sections, as shown in Fig. 18-20. The *T*-type filter has the same total inductance and capacitance as the π -type. Each of the series capacitors in the *T* filter has twice the capacity of the capacitor in the π filter. Because they are connected in series in the *T* filter, the two capacitors have a total capacity equal to the single capacitor in the π filter. Each of the two shunt inductors in the π filter has twice the inductance of the inductor in the *T* filter. However, because they are connected in parallel, the π -filter inductors have the same total inductance as the single inductor in the *T* filter. Two or more *T*- or π -filter sections may be used to provide sharper cutoff. Figure 18-21 shows two filters: one of two *T* sections and one of two π sections.

18-4. BAND-PASS FILTERS

As we said in the beginning of this lesson, a band-pass filter is one that permits a certain band of frequencies to pass and stops all other frequencies above and below this band. As you already know, a series-resonant circuit may be used as a band-pass filter. When connected as in Fig. 18-22a, a circuit offers minimum opposition to the a.c. of

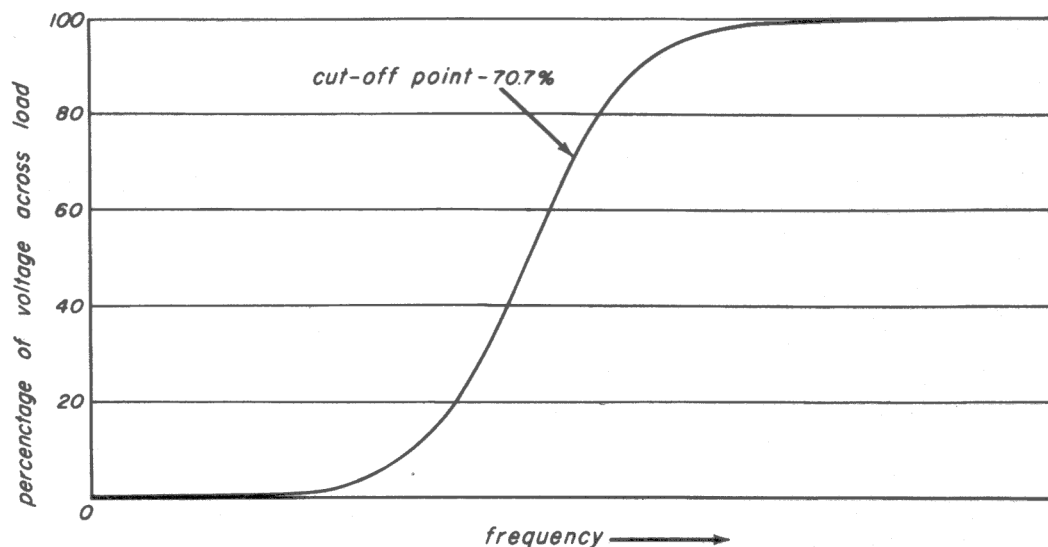
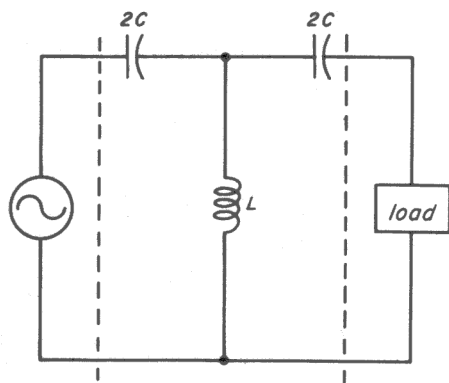
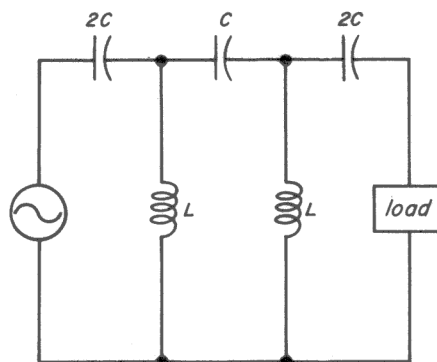


Fig. 18-19



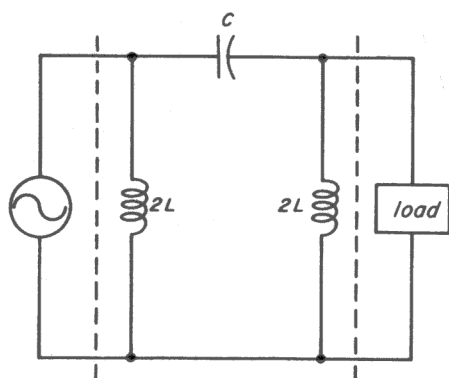
T-type high-pass filter

(a)

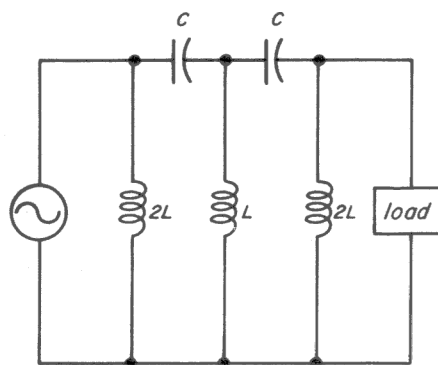


two-section high-pass T filter

(a)

 π -type high-pass filter

(b)

two-section high-pass π filter

(b)

Fig. 18-20

the resonant frequency and increasingly greater opposition as the frequency rises or falls from the resonant frequency. Also, a parallel-resonant circuit may be used as a band-pass filter. When such a circuit is connected in shunt with the load, as in Fig. 18-22b, the resonant frequency a.c. passes to the load, while lower frequencies are bypassed through the low reactance that the inductor offers to these frequencies; the higher frequencies are bypassed through the low-reactance that the capacitor offers to high frequencies.

A typical transmission curve for a band-pass filter is shown in Fig. 18-23. The band of frequencies that pass is called the *band-pass* or *bandwidth*. The bandpass may be widened — that is the number of frequencies that is passed can be increased — by reducing the Q of either the series-resonant circuit or the parallel-resonant circuit. This may be done by adding resistance to either circuit, as shown in Fig. 18-24. Then the transmission curve (Fig. 18-25) shows that

Fig. 18-21

the voltage reaching the load is decreased while the bandpass is increased.

To sharpen the cutoff and narrow the band-pass, a series circuit and a parallel resonant circuit may be combined, as in Fig. 18-26a. The transmission curve for such a filter is shown in Fig. 18-26b.

18-5. BAND-REJECTION FILTERS

As you learned in the beginning of this lesson, a band-rejection filter blocks a certain band of frequencies and permits all other frequencies to pass. Such a filter works in a way that is exactly opposite to a band-pass filter. The simplest form of band-rejection filter is either a parallel-resonant circuit connected as in Fig. 18-27a or a series-resonant circuit connected as in Fig. 18-27b. Either circuit is tuned to the unwanted band of frequencies. The parallel resonant circuit offers maximum impedance to the unwanted

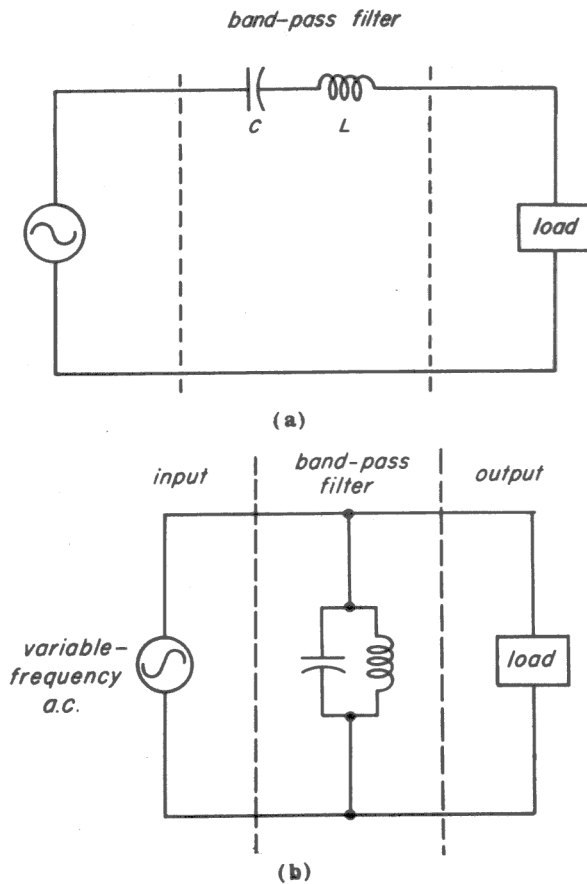


Fig. 18-22

frequencies, so that most of the voltage at such frequencies appears across the parallel resonant circuit and does not reach the load. Such a circuit is sometimes called a *wave-trap*. The series resonant circuit offers minimum impedance to the unwanted frequencies, which causes them to bypass the load. A typical transmission curve for a band-rejection

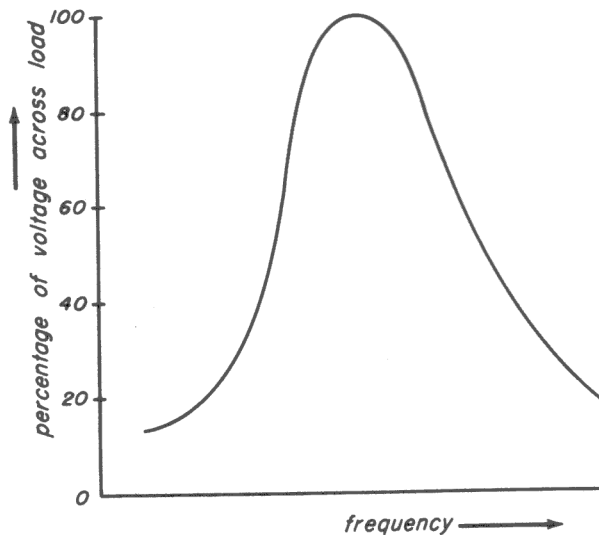


Fig. 18-23

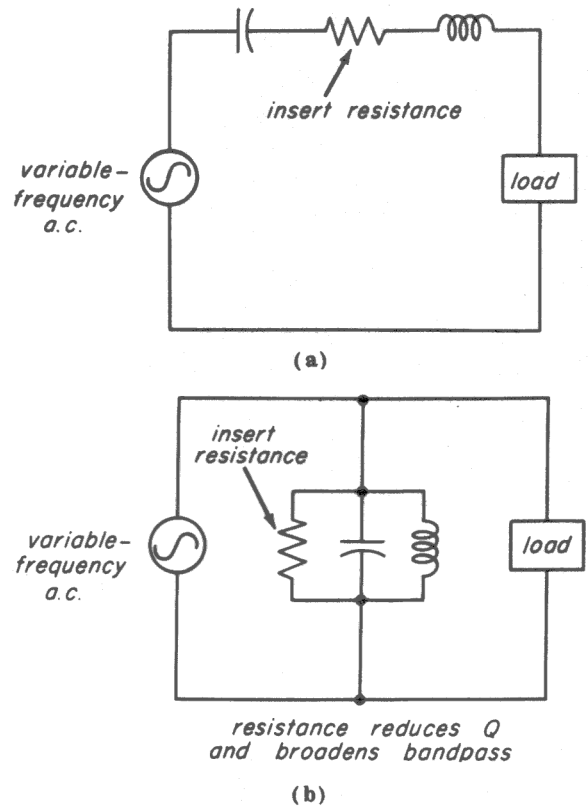


Fig. 18-24

tion filter is shown in Fig. 18-27c. Combining these two circuits, as we did with the bandpass filter, provides sharper cutoff and narrower bandwidth. (Fig. 18-28).

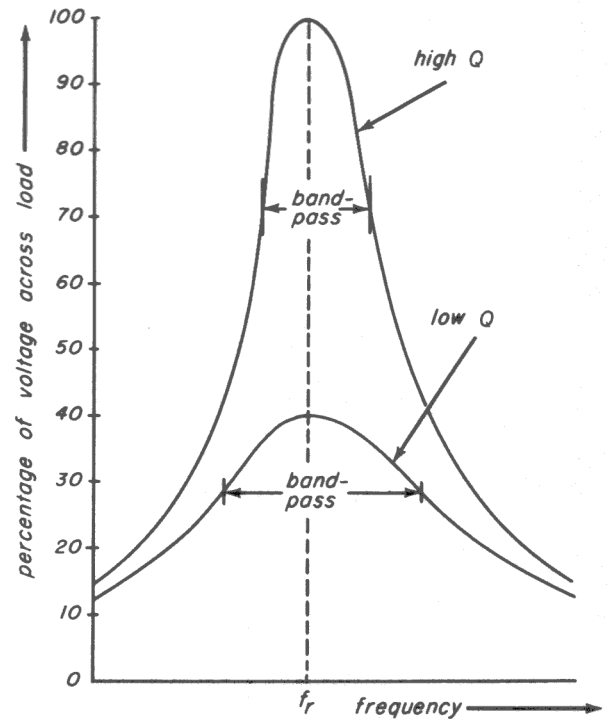
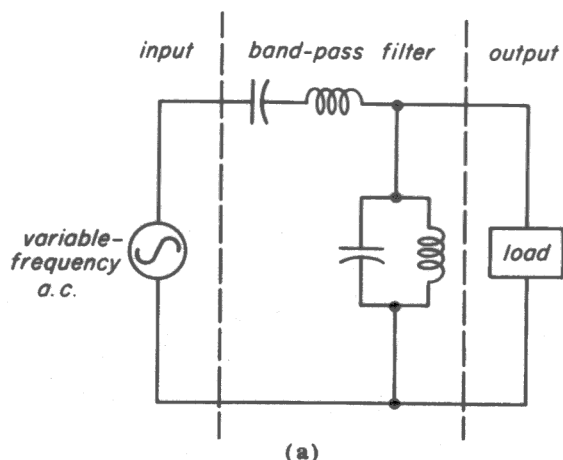


Fig. 18-25

18-6. TIME CONSTANTS

Our knowledge of what happens in many radio and television circuits, including certain filter circuits, depends on our understanding of *time constants*. Now is a good time to learn what time constants are and how we may use them. There are two time constants: one is called the RC time constant and the other is the L/R time constant. Because you will find greater use for a knowledge of the RC time constant, let us study it first.

Before we say what a time constant is, let us review some things that you already know.



(a)

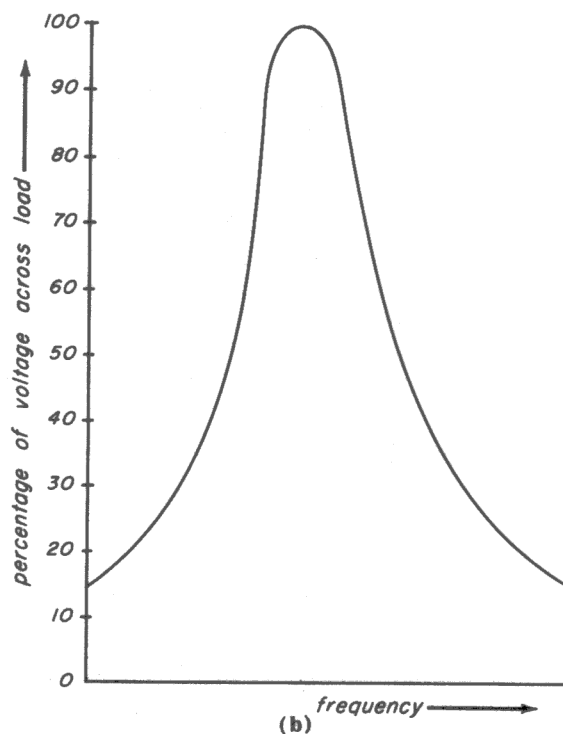
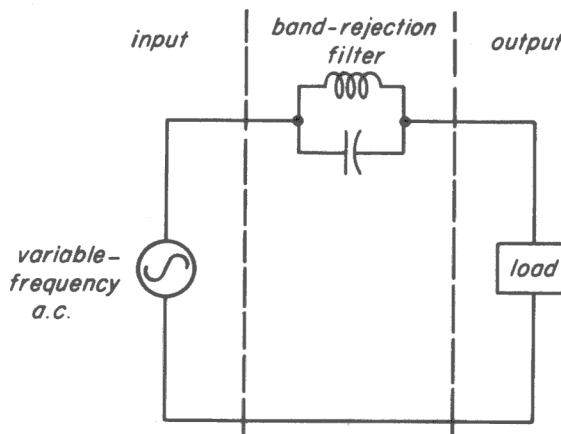
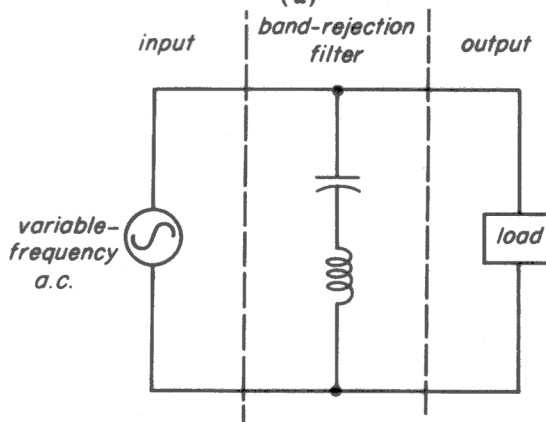


Fig. 18-26

Look at the circuit shown in Fig. 18-29a. When switch *A* is closed, a large current flows for an instant, and the capacitor charges to the full value of the applied voltage al-



(a)



(b)

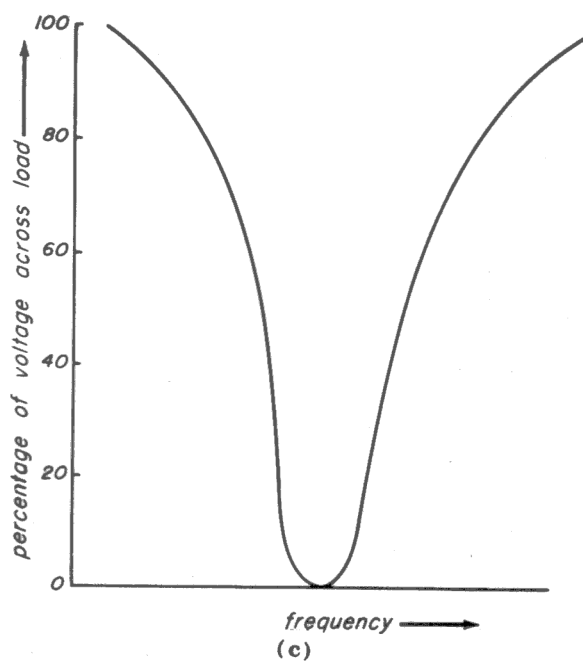


Fig. 18-27

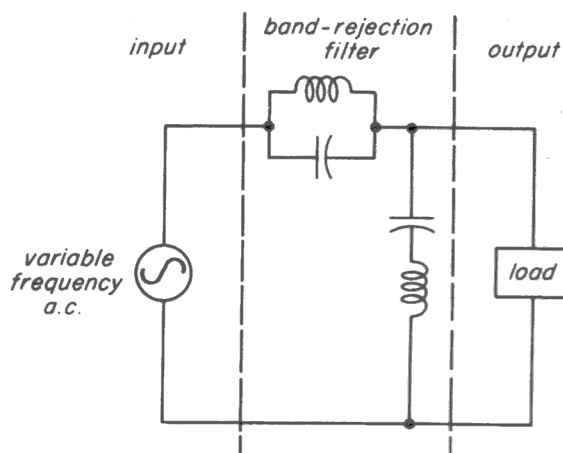
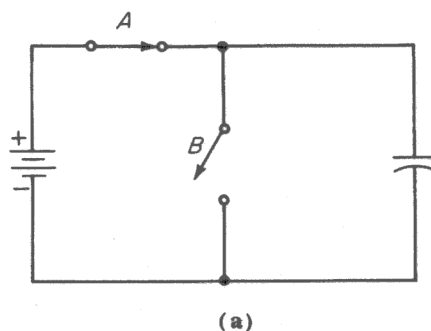


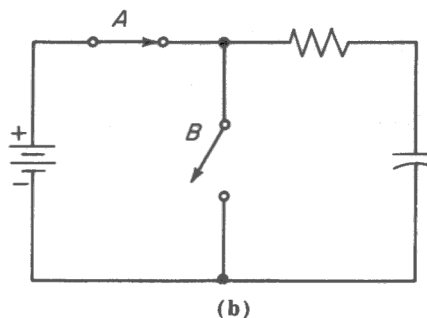
Fig. 18-28

most immediately. In fact, unless there is an unusual amount of resistance in the circuit due to the length and cross section of the conductor, the condition of the switch contacts, or the condition of the battery, we can ignore the very small amount of time it takes for the capacitor to reach full charge and say that, for all practical purposes, the capacitor takes no time at all to charge.

However, let us insert resistance in the circuit, as in Fig. 18-29b. From your study of resistance and d-c circuits, you know that when current flows through a resistor, there is a voltage drop across the resistor. To charge the capacitor, current must flow through the resistor. This being so, the capacitor cannot charge to the full value of



(a)



(b)

Fig. 18-29

the applied voltage as soon as switch *A* is closed, because at least some of the voltage must drop across the resistor. In fact, at the instant switch *A* is closed, the *entire* voltage appears across the resistor. As current starts flowing, the capacitor begins to charge. Look at the curve of the charging current (Fig. 18-30). It shows that the charging current reaches 100 percent of its maximum value almost immediately after the switch is closed. As the capacitor charges, the current *decays* (drops) rapidly at first and

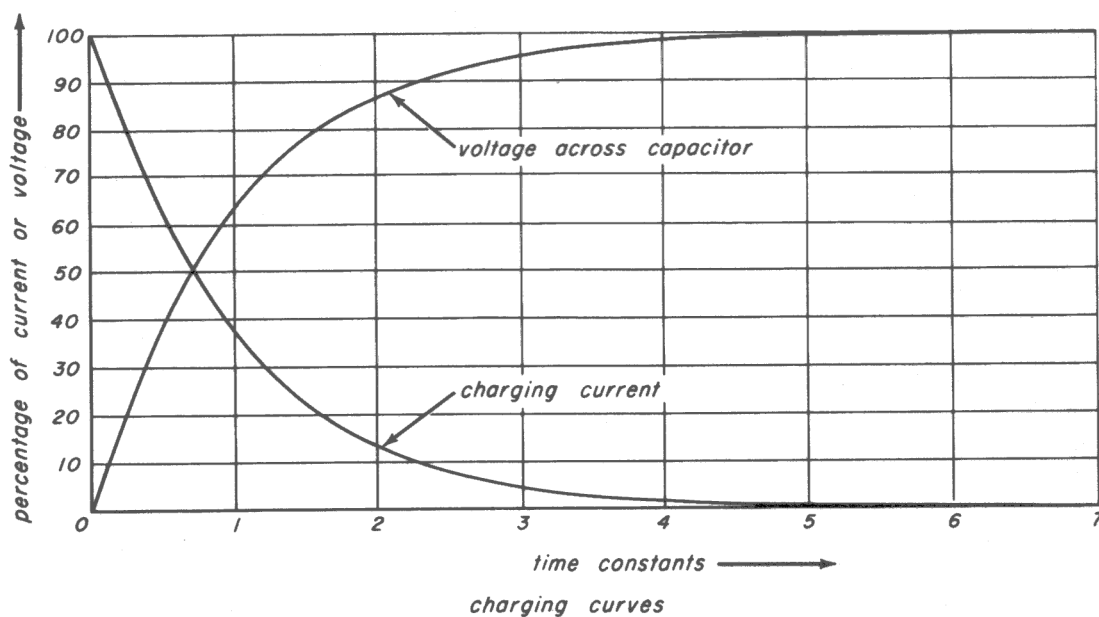


Fig. 18-30

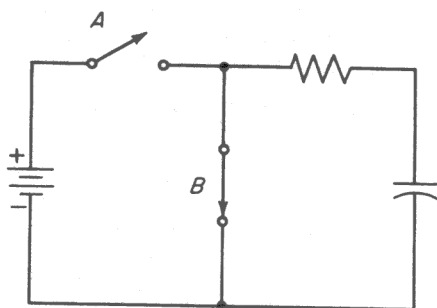


Fig. 18-31

tapers off until it reaches zero as the capacitor becomes fully charged. As the current decreases, the voltage drop across the resistor becomes less. When the current stops flowing, the voltage across the resistor becomes zero. While all this is happening, the voltage across the capacitor (see Fig. 18-30) climbs rapidly from zero until it reaches 100 percent of the applied voltage. At this point, we say that the capacitor is fully charged.

From this you can see that the resistance of the circuit causes some time delay in charging the capacitor. Look again at the curves of Fig. 18-30. Note that the horizontal axis is laid off in equal units of time. Note, too, that charging current decays 63.2 percent of its maximum value and the voltage across the capacitor rises 63.2 percent of its maximum value in the first of these time units. During the next equal time unit, the current decays 63.2 percent of the remaining 36.8 percent. If we multiply 36.8 by 0.632, we find that the current drops about 23.3 percent more — making a total decay of 86.5 percent in two time units. In the same two units of time, the charge on the capacitor reaches 86.5 percent of full charge. In each of the following time units, the current decays and the charge rises 63.2 percent of the remainder. So, as you can see in the curves of Fig. 18-30, 95 percent is reached in the third time unit, 98.2 percent in the fourth time unit, 99.3 percent in the fifth time unit, 99.7 percent in the sixth time unit, and 99.9 percent in the seventh time unit.

Suppose that we now reverse the process and discharge the capacitor through the same resistor (Fig. 18-31) by opening switch A and closing switch B. The current rises instantly as switch B is closed and decays rapidly at first and then gradually tapers

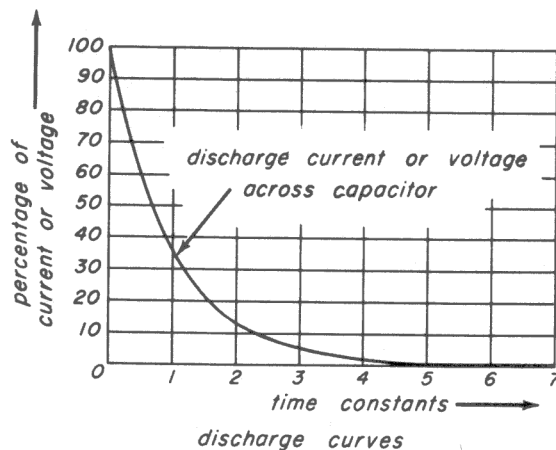


Fig. 18-32

off as during the charging cycle. In fact, the current discharge curve (Fig. 18-32) is the same as the current charge curve. When switch B is closed, the capacitor is at 100 percent of full charge. Immediately, the voltage across the capacitor starts dropping, rapidly at first and then gradually tapering off until the capacitor is fully discharged.

We can now define the RC time constant. We can define it in two ways: the RC time constant is the time required for a capacitor to reach 63.2 percent of full charge, when charging through a resistor, or it is the time required for the capacitor to lose 63.2 percent of full charge, when discharging through a resistor. So, the time units that we used on the horizontal axis of the curves in Figs. 18-30 and 18-32 are actually time constants. While each curve shows changes in current or charge for a period of seven time constants, the time necessary to charge or discharge a capacitor through a resistor is considered to be five time constants. At the end of the fifth time constant, the capacitor is 99 percent charged or discharged (depending on which action is taking place), which is close enough to 100 percent for all practical purposes.

The time constant of any combination of R and C may be found by using this formula:

$$t = RC$$

where:

t = time in seconds

R = resistance in ohms

C = capacitance in farads

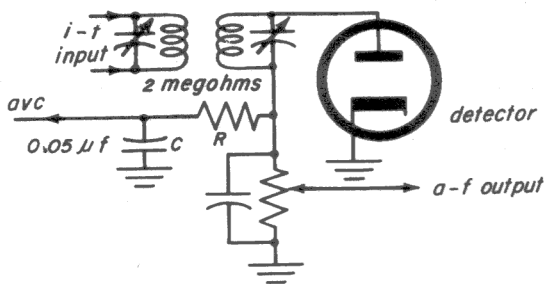


Fig. 18-33

A more useful form of the formula expresses R in megohms and C in microfarads, in which case, t is still in seconds. For example, let's find the time constant of a 0.5-megohm resistor and a 3- μ f capacitor:

$$\begin{aligned} t &= R C \\ &= 0.5 \times 3 \\ &= 1.5 \text{ sec.} \end{aligned}$$

The capacitor would take 5 times 1.5 or 7.5 seconds to charge or discharge through the resistor.

Of what value is such information to us? How can we use it? One practical use is in an automatic-volume-control (AVC) circuit, such as used in most radio and a similar circuit used in television receivers. Figure 18-33 shows a typical AVC circuit. Some of the rectified output of the diode detector is filtered by the low-pass RC filter made up of the 2-megohm resistor R and the 0.05- μ f capacitor C . The filtered voltage provides what is called *bias* potential for certain tubes. Bias is discussed fully in later lessons. For now, it is necessary only that you know that this bias voltage should be in proportion to the strength of the signal being received and that it should not vary in value due to any changes in the sound frequencies that are part of the rectified signal voltage. The RC filter must remove these variations and pass on to the tubes a bias voltage that is practically pure d.c. The values of R and C are chosen with a time constant that is long enough that the audio (sound) variations cause little or no change in the charge on the capacitor (bias voltage), while slower changes in signal strength, such as caused by fading, will cause a change in bias.

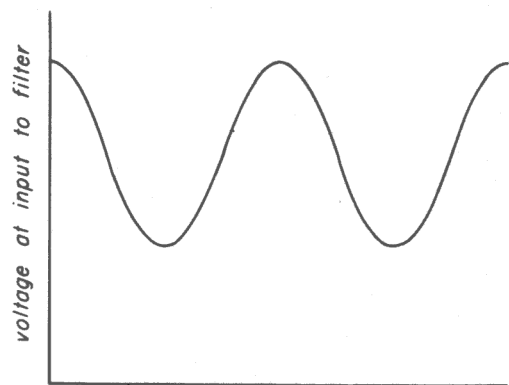


Fig. 18-34

Let's see how a resistor and capacitor combination with the right time constant works as an AVC filter. Figure 18-34 represents the voltage that appears at the input to the filter. This voltage is d.c. that varies in amplitude at an audio rate. We'll say that the audio frequency is 100 cps. Therefore, each cycle lasts 1/100 sec. Our RC filter has a time constant of 1/10 sec ($t = 2 \times 0.05$) and it takes the capacitor five time constants or 0.5 sec to charge. Starting at the moment when the capacitor is charged to the peak value of the rectified signal voltage (point A of the curve in Fig. 18-35) we can begin to see how the time constant affects the filtering action. As soon as the charging voltage starts to drop after point A , the capacitor starts to discharge, as shown by the dotted line from point A to point B . As you know, it would take one time constant (1/10 sec) for the voltage to drop 63.2 percent of its peak value. But in 1/100 sec, the charging voltage reaches a positive peak and charges the capacitor up to peak value again. This means that the capacitor doesn't have time enough to discharge more than a

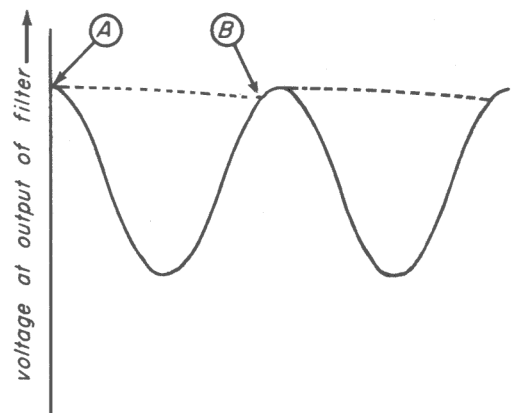


Fig. 18-35

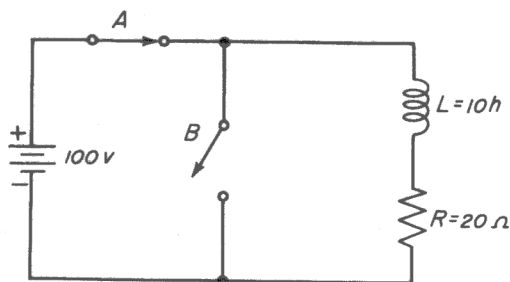


Fig. 18-36

little bit before the next charging cycle recharges it. So the voltage across the capacitor is not affected much by any changes in amplitude that occur at an audio rate. However, if the signal should become stronger or weaker and the rectified voltage at the input to the RC filter should rise or fall in value for a tenth of a second or so, the charge on the capacitor would change and so change the bias voltage. If the time constant of the RC filter were to be too long, the bias voltage could not be adjusted in time to allow for changes in signal strength that last only a quarter of a second or so.

The L/R Time Constant. In an LR circuit, there is a time delay between the time voltage is applied and the time when maximum current flows. When switch A is closed in an LR circuit such as that in Fig. 18-36, the charging current causes a counter emf that delays the current from reaching its maximum value. This being a d-c circuit, maximum current flows when the counter emf stops forming and the only opposition is due to resistance. The smaller the inductance and the greater the resistance, the shorter is the delay; while the greater the inductance and the smaller the resistance, the longer is the delay. So, the L/R time constant may be found by this formula:

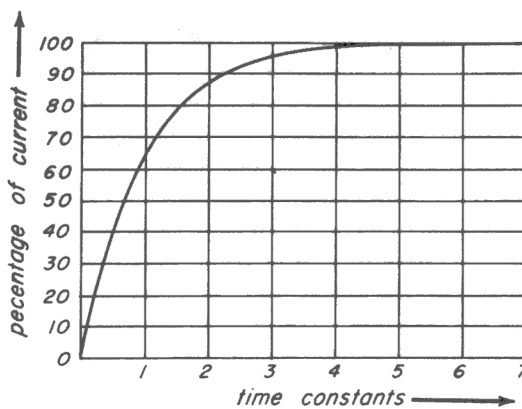
$$t = \frac{L}{R}$$

where:

t = time in seconds

L = inductance in henrys

R = resistance in ohms



charge curves

Fig. 18-37

Using the values of resistance and inductance shown in Fig. 18-36, we can use the formula to find the LR time constant:

$$\begin{aligned} t &= \frac{L}{R} \\ &= \frac{10}{20} \\ &= 0.5 \text{ sec.} \end{aligned}$$

If the applied voltage is 100 volts, the maximum current equals:

$$\begin{aligned} I &= \frac{E}{R} \\ &= \frac{100}{20} \\ &= 5 \text{ amps} \end{aligned}$$

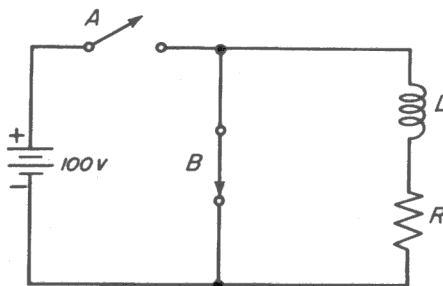


Fig. 18-38

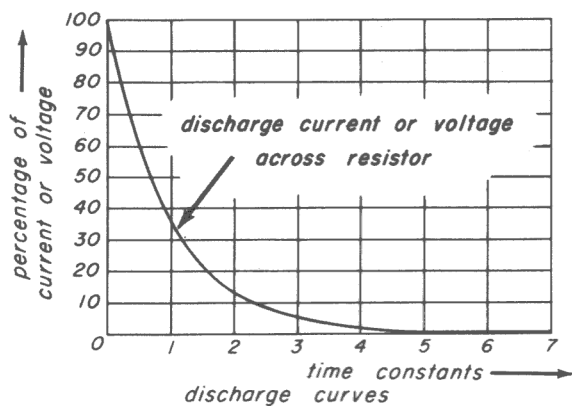


Fig. 18-39

At the end of one time constant (0.5 sec), the current will reach 63.2 percent of 5 amps. or 3.16 amps, as shown by the curve

of Fig. 18-37. For all practical purposes, the current reaches its maximum value at the end of five time constants (2.5 sec).

When switch *A* is opened and switch *B* is closed, as shown in Fig. 18-38, the magnetic field collapses and produces a current that flows in the same direction as the original line current, as shown in Fig. 18-39. At the first instant, the current will be maximum (5 amps, or 100%, Fig. 18-39) and at the end of one time constant (0.5 sec) it will drop 63.2 percent to 1.84 amps. At the end of five time constants (2.5 sec) the current will cease flowing.